Clamp-On Flow-Velocity and Density Transducers for Cryofluids in Thin-Walled Conduits

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In principle, it seems possible to measure the mass flow rate, M_f, of cryofluids under single-phase and under some two-phase conditions using external acoustic or ultrasonic transducers that clamp onto the outside of the conduit without penetrating or thinning the conduit. The mass flow rate velocity measurement would consist of a combination of flow (V) sensors and fluid density (ρ) sensors. The flow sensors utilize contrapropagation for fluid that is substantially single-phase, but utilize stroboscopic tracking of scatterers in a reflection mode when bubbles in the fluid scatter the interrogating wave so much that the signal-to-noise ratio obtained with wall-to-wall transmission is inadequate. The fluid density sensors utilize a mass-loading effect on flexural (bending) waves. Reference figure 106.

The near-term objective of this program is to measure flow and mass flow rate in stainless steel and Inconel ducts having diameters near 33 millimeters and near 100 millimeters and wall thickness near 3 millimeters. For this wall thickness, one is able to take advantage of utilizing the small clamp-on ultrasonic transducer developed under contract NAS8–38429 to measure flow either

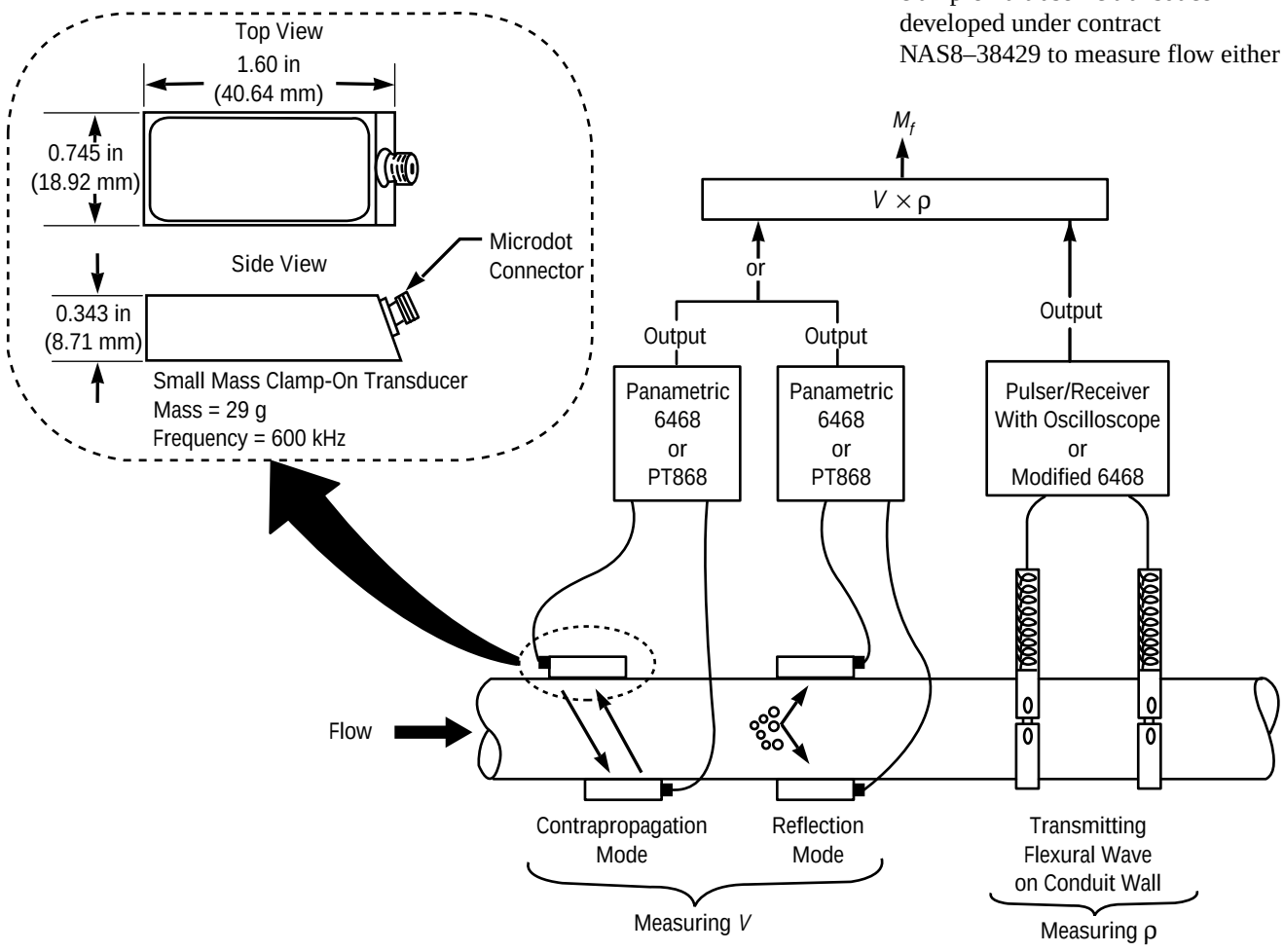

FIGURE 106.—Test configuration to determine mass flow rate.

in the contrapropagation or the reflection mode of the interrogation. In the contrapropagation mode, the clamp-on transducer operates satisfactorily as long as the cryofluid (liquid nitrogen) is single-phase and the flow condition is not "too violent."

Preliminary piggyback testing with liquid oxygen flowing in the high-pressure oxidizer turbopump discharge duct (4.37 inches in diameter by 175 inches in width) and in the fuel preburner supply (1.996 inches in diameter by 127 inches in width) of the space shuttle main engine at the MSFC test stand showed that the transducers operated in conjunction with two commercial ultrasonic flow meters (Panametrics Models 6468 and PT868. Although they have some difficulty measuring flow in the contrapropagation mode, these meters survive the vibration of the duct and the cryogenic temperature of the liquid oxygen).

When the cryofluid is not single-phase, it will have scatterers for the reflection mode of interrogation. A simple test where air bubbles were introduced into water inside a pipe capped at one end demonstrates that this transducer is also able to detect the bubbles as reflectors.

The clamp-on density sensors, in contrast to the flow sensors, do not depend on the continuity of the fluid in the pipe. These sensors are attached orthogonally to the pipe. If operated at a sufficiently low frequency, or stated equivalently, at a sufficiently long flexural wavelength, λ_{flex}, the fluid density sensors launch and detect bending or flexural waves having a phase velocity, c_{flex}, that—for a given pipe—depends on the average density of the fluid in the pipe, or the amount of a given liquid in the pipe. This latter dependence is the basis for liquid presence/liquid level (H) sensing. Analysis of phase velocity in a 1-inch stainless-steel pipe (dia. >> λ_{flex}) and in a flat stainless-steel plate (tank "dia." >> λ_{flex}) has now been carried to the point of explaining the main observations.

More testing is needed to determine the limitations of (1) the operation of the clamp-on transducer in the contrapropagation and reflection mode when cryofluid is single- and two-phase, respectively, and (2) the performance of the clamp-on density sensor in detecting cryofluid density/void fraction. The test will be performed first in a laboratory water-flow loop where conditions are easily controlled. Later the test will be conducted on the liquid-oxygen duct of the space shuttle main engine at the MSFC test stand.

Lynnworth, L.C.; Nguyen, T.H.; Liu, Y.; and Stein, P. September 1994. Clamp-On Flow Velocity and Density Transducers for Liquid Nitrogen and Other Cryogenic Applications, Especially in Thin-Walled Conduits. 1994 Conference on Advanced Earth-to-Orbit Propulsion Technology, vol. 1:97–104.

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